Catalytic Iridium-based Janus Micromotors Powered by Ultralow Levels of Chemical Fuels

Wei Gao, Allen Pei, Renfeng Dong, Joseph Wang*

Department of Nanoengineering, University of California, San Diego, La Jolla, California 92093, United States.

* Address correspondence to josephwang@ucsd.edu.

Supporting Videos

SI Video 1. The propulsion of catalytic Janus Ir/SiO_2 micromotors in 0.001% hydrazine.

SI Video 2. Motion of Pt/SiO_2 in the presence of 10 % and 1 % hydrogen peroxide fuel, Ir/SiO_2 and Ir/PS Janus micromotors in the presence of 0.001% hydrazine.

SI Video 3. The propulsion of Ir-based titania coated PS micromotors in the presence of 0.001% hydrazine.

SI Video 4. Dependence of the speed of Ir/SiO_2 Janus micromotors upon the hydrazine concentrations.

SI Video 5. Magnetic control of multi-layer Ir-TiO_2-Ni-Ti-SiO_2 Janus micromotors in 0.001% hydrazine.

SI Video 6. The swarming behavior of Ir-based Janus micromotors (4.74 µm) in 0.001% hydrazine.

SI Video 7. The pumping behavior of Ir-based Janus micromotors (4.74 µm) swarms with passive tracer (1.2 µm) in 0.001% hydrazine.

Experimental Section

Synthesis of Janus micromotors. The Janus micromotors were prepared using silica microparticles (1.21 µm and 4.74 µm mean diameter, Bangs Laboratories, Fishers, IN, USA) and polystyrene microparticles (0.91 µm mean diameter, Spherotech, Lake Forest, IL, USA) as the base particles. 10 µL of silica particles were first dispersed into ethyl alcohol (A407-4, Fisher, Pittsburgh, PA, USA) and centrifuged. Then, the silica particles were redispersed in 150 µL ethyl alcohol. The sample was then spread onto glass slides and dried uniformly to form particle monolayers. The particles were sputter coated with a very thin Ir layer (~20 nm) using an Emitech K575X Sputter Coater for 3 cycles with 10 s per cycle (5 cycles for particles with a diameter of 4.74 µm). Pt-SiO_2 Janus particles were sputter coated with a 20 nm Pt layer using a Denton Discovery 18 sputter coater. The deposition was performed at room temperature with a DC power of 200 W and Ar pressure of 2.5 mT for 15 s. In order to obtain a uniform Janus half-shell coating, rotation was turned off and the sample slides were set up at an angle to be parallel to the Pt target. The resultant optimal thicknesses of Pt and Ir layers of the Janus micromotors (1.2 diameter) are 20 nm and 10 nm, respectively (as measured by Veeco DEKTAK 150 Profilometer). After the fabrication, the Janus particles were detached from the substrate *via* sonication or pipette pumping and were mixed with an aqueous solution of hydrazine. For the magnetic Janus motors, silica particle monolayers were prepared as above. A 10 nm layer of Ti followed by a 15 nm layer of Ni were sequentially deposited on half of the particles by electron beam evaporation (Temescal BJD 1800 Ebeam Evaporator). Then, a conformal coating of TiO_2 was deposited on the particles by atomic layer deposition (ALD) (Beneq TFS200) at 100°C for 1000 cycles. The final Ir coating was sputter coated as above. Polystyrene S particles (AP-08-10 and CM-08-10 from Spherotech, Lake Forest, IL) with an Ir Janus layer were prepared similarly.

Reagents and solutions. Hydrazine and hydrogen peroxide solutions are purchased from Sigma (# 309400) and Fischer (# H325-100), respectively. In order to propel the catalytic Janus particles, aqueous hydrazine and hydrogen peroxide solutions with concentrations ranging from 0.00000001% to 10 % were prepared and used as chemical fuels. The propulsion experiments were carried out by mixing 3 µL of the motors (taken from glass slides by pipette) and 3 µL hydrazine solutions.

Equipment. Videos were captured by an inverted optical microscope (Nikon Instrument Inc. Ti-S/L100), coupled with 40× objectives, and a Hamamatsu digital camera C11440 using the NIS-Elements AR 3.2 software. pH values of the aqueous solutions were measured with Five-Easy pH meter (Mettler Toledo, Inc., Columbus, OH, USA).